



Vizualizace infarktu myokardu v prostředí Android

Bakalářská práce

Studijní program: B3944 – Biomedicínská technika
Studijní obor: 3901R032 – Biomedicínská technika
Autor práce: **Jana Stárková**
Vedoucí práce: Ing. Jana Kolaja Ehlerová, Ph.D.





Visualization of Myocardial Infarction in Android

Bachelor thesis

Study programme: B3944 – Biomedical Technology
Study branch: 3901R032 – Biomedical Technology
Author: **Jana Stárková**
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Zadání bakalářské práce

Vizualizace infarktu myokardu v prostředí Android

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Zásady pro vypracování:

Cíle práce:

1. Describing pathophysiological changes in human heart during myocardial infarction. Selecting appropriate processes suitable for visualisation and specifying application requirements for target group
2. Researching existing applications for human heart visualization
3. Analytic tools and model formats suitable for heart visualising
4. Proposing and creating the mobile application prototype, application testing with a group of target users

Teoretická východiska (včetně výstupu z kvalifikační práce):

The outcome of the thesis will be a mobile application which will visualize anatomical model of the human heart. The model will be three dimensional; it will simulate the contractions as well as tissue necrosis resulting from myocardial infarction. Visualisation helps better understanding of an issue; therefore, it is expected to improve educational methods.

Výzkumné předpoklady / výzkumné otázky:

We plan to create a mobile application which will simulate pathophysiological processes in human heart during myocardial infarction.

Metoda:

Experimental, software development.

Technika práce, vyhodnocení dat:

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3. 5. 2019

Jana Stárková

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Abstrakt

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Anotace: Bakalářská práce je zaměřena na vývoj prototypu mobilní aplikace, jejíž cílem je vizualizovat patofyziologické procesy při infarktu myokardu. Součástí práce je nastudování patofyziologických dějů v srdci a vybrání dějů vhodných pro vizualizaci. Dále pak shrnutí současných mobilních aplikací, které se věnují problematice infarktu myokardu, a identifikování klíčových aspektů aplikace. Nedílnou součástí práce je také tvorba grafických 3D modelů srdce, jejich animace, export a implementace do mobilní aplikace.

Klíčová slova: srdeční cyklus, ischemie, infarkt myokardu, 3D vizualizace, Android, mobilní aplikace

Abstract

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Institution: Technical University of Liberec, Faculty of Health Studies

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Annotation: The bachelor thesis is aimed at the development of a mobile application prototype. The thesis starts with learning about the pathophysiological processes in heart and selecting appropriate processes for visualization. Further, we summarize the state-of-the-art of currently available applications focused on myocardial infarction and identify the key aspects of our application. The main part of the thesis is creating graphic 3D models of the heart, animating them and implementing in the mobile application.

Keywords: cardiac cycle, ischemia, myocardial infarction, 3D visualization, Android, mobile application

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List of Used Abbreviations

3D	three dimensional
aa.	arteriae
ACS	acute coronary syndrome
approx.	approximately
bpm	beats per minute
cm	centimetre
CPR	cardiopulmonary resuscitation
ECG	electrocardiogram
etc.	et cetera
LDL	low-density lipids
mm	millimetre
mmHg	millimetre of mercury
NSTEMI	non ST-segment elevation myocardial infarction
PCI	percutaneous coronary intervention
RC	ramus circumflexus
RIA	ramus interventricularis anterior
RIP	ramus interventricularis posterios
STEMI	ST-segment elevation myocardial infarction
v.	vena

1 Introduction

Bachelor thesis on the topic of Visualization of Myocardial Infarction in Android is aimed at developing a mobile application prototype which will visualize pathophysiological processes in the human heart during myocardial infarction. The inspiration for this topic came from the non-profit organisation Loono which desired an additional educational tool that could be used during their workshops aimed at preventative care in cardiovascular diseases. The result of the thesis is an Android application which is a prototype of an educational application about myocardial infarction.

The majority of the theoretical part of the bachelor thesis is aimed at the topics important for understanding the issue of myocardial infarction. Before creating and animating 3D model visualising the myocardial infarction, it is essential to fully comprehend the function of a healthy heart from the anatomical and physiological aspects. That means understanding the structure of both atria and ventricles as well as the of coronary arteries. It is followed by the cardiac cycle and the electrical conduction system of the heart. We also focused on the pathophysiology of myocardial infarction and its classification. Further, we briefly describe the diagnosis of myocardial infarction followed by its treatment. The last topic is a state-of-the-art of mobile applications focused on myocardial infarction visualizing.

The practical part of the bachelor thesis begins with an overview of the 3D model used for visualization as well as the description of the remodelling process. It summarises the animation procedure together with technical parameters needed for that matter. Further, it contains the concept of our Android application which is used for education through displaying and describing the 3D models. Within the scope of the practical part, the actual Android application was developed and tested among a target group of users.

Within the discussion, we evaluate our outcomes and we also carry out recommendations for further practice.

In conclusion, the results of the bachelor thesis are evaluated and summarized.

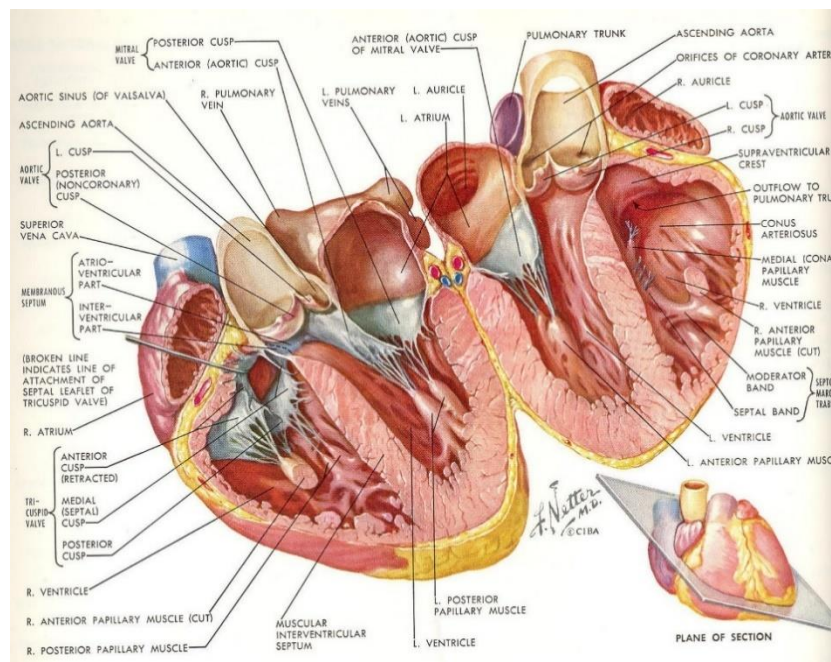
2 Theoretical Part

2.1 The heart

The heart is a muscular organ consisting of four chambers – two atria and two ventricles (see Picture 1). It is divided into the right and the left part; the right part is filled with the deoxygenated blood while the left atrium and ventricle are filled with oxygenated blood. The heart continually pumps and allows supplying the body with nutrition and oxygen as well as enables local metabolism in tissues (Trojan, 2003).

The heart of an adult weight approximately from 230 to 340 grams. Woman's heart is slightly lighter; it is said to weight around 0,4% of total bodyweight while man's is reaching 0,45% of total body weight. Weight of the heart is also dependant on the patient's age and amount of myocardium (Čihák, 2016).

According to Čihák (2016), the heart is positioned in the pericardial cavity in the inferior middle mediastinum behind the sternum. The pericardia imprint is visible in both lungs; the inferior surface is adjacent to the diaphragm.



Picture 1: The atria and ventricles of the heart (Netter, 2003, str. 212).

2.1.1 Right Atrium

The right atrium or so-called atrium dextrum is associated with two significant veins – vena cava superior and vena cava inferior, which collect the deoxygenated blood from the whole body. They both enter the atrium in the lateral part, v. cava superior being approximately 2 centimetres wide at its ostium and v. cava inferior approximately 3 to 3,5 centimetres (Čihák, 2016).

The remaining foramen ovale can be found in the interatrial septum. There are two veins that have valves at their entry to the right atrium, that being sinus coronarius which represents the largest cardiac vein and v. cava inferior (Paulsen a Waschke, 2011).

2.1.2 Right Ventricle

The ventriculus dexter begins with the atrioventricular tricuspid valve which separates the atrium from the ventricle and ends with the semilunar pulmonary valve. It is filled with deoxygenated blood which flows through the tricuspid valve from the right atrium and is pushed to the pulmonary circuit through the pulmonary valve. The valva tricuspidali is attached to the muscoli papillares which prevent it from reverting into the atrium (Čihák, 2016).

2.1.3 Left Atrium

The atrium sinistrum is a smooth chamber which has approximately 3 millimetres thicker walls than the right atrium. It is filled with oxygenated blood that inflows to the atrium from the lungs through four pulmonary veins. The septum interatriale is very thin, almost transparent from the left view in the area of foramen ovale. The left atrium pushes the oxygenated blood to the left ventricle through the bicuspid aortic valve (Čihák, 2016).

2.1.4 Left Ventricle

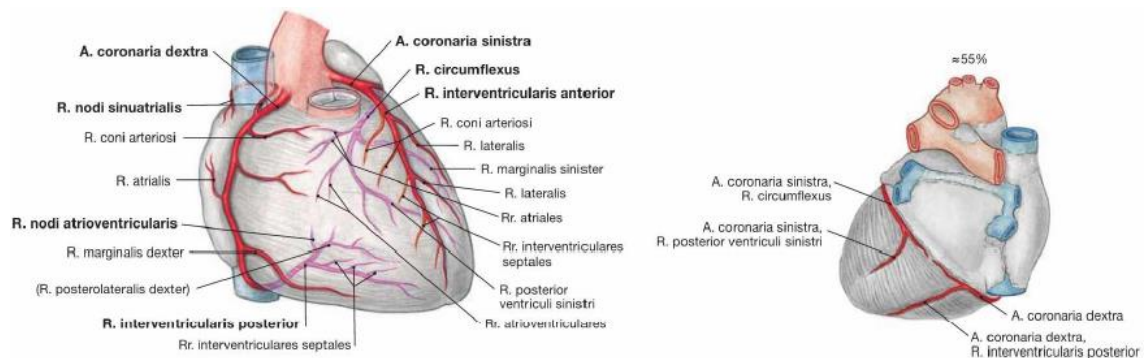
According to Čihák (2016), the left ventricle has a much thicker muscle layer than the right ventricle due to the fact that its muscles push against higher pressure during its contraction. Further, it is longer and narrower than the right ventricle.

Each of the cusps of the mitral valve is attached to a papillary muscle. The cardiac muscle fibres fill the major part of the intraventricular septum (Paulsen a Waschke, 2011). The blood from the left ventricle is pushed through the aortic valve which consists of three semilunar valves. The blood is ejected to the aorta, thus, to the whole body (Čihák, 2016).

2.1.5 Coronary vessels

The blood and nutrition supply of the heart itself is provided by the coronary arteries. Specifically, there are the left coronary artery (*arteria coronaria sinistra*) and the right coronary artery (*arteria coronaria dextra*). They are the branches of the aorta and they lay on top of the heart in a layer of a thin ligament and fat (Čihák, 2016).

Čihák (2016) says that the coronary arteries are characterised by their curvy progression which follows the surface of the heart. The branches of each artery are adherent to the myocardium with ties and bridges (*vincula, ponticula*). The progression of the arteries, their branching and the supplying area varies among the population. The dominance of the coronary arteries is based upon the position of the *ramus interventricularis posterior* (which is a branch of the *arteria coronaria dextra*) (Picture 2). According to Paulsen and Waschke (2011), the balanced (co-dominant) coronary circulation is the most widespread arrangement of the arteries, it can be observed in 55% of cases.



Picture 2: The balanced (co-dominant) coronary circulation. The most important branches of each coronary artery (Dalkowski et al., 2011, str 26).

The main purpose of the coronary veins is to collect the blood from the cardiac muscle and lead it inside of the heart. The vast majority of the coronary veins empties into the right atrium, only the veins which join the *venae cordis minimae* empty out to all of the chambers (Čihák, 2016). Because the coronary veins do not supply the heart with oxygen and thus do not play a major role in myocardial infarction, they are not in the interest of our bachelor thesis.

2.1.6 Electrical Conduction System of the Heart

The cells within a heart with an ability to autonomously generate and lead the electric charge are called the cardiac pacemaker cells and together they create the electrical conduction system. The other type of cardiac cells, the cardiomyocytes (cardiac muscle cells), compose a working myocardium whose main function is to contract; they generate electric charge only when affected by pathologic processes (Hampton, 2013).

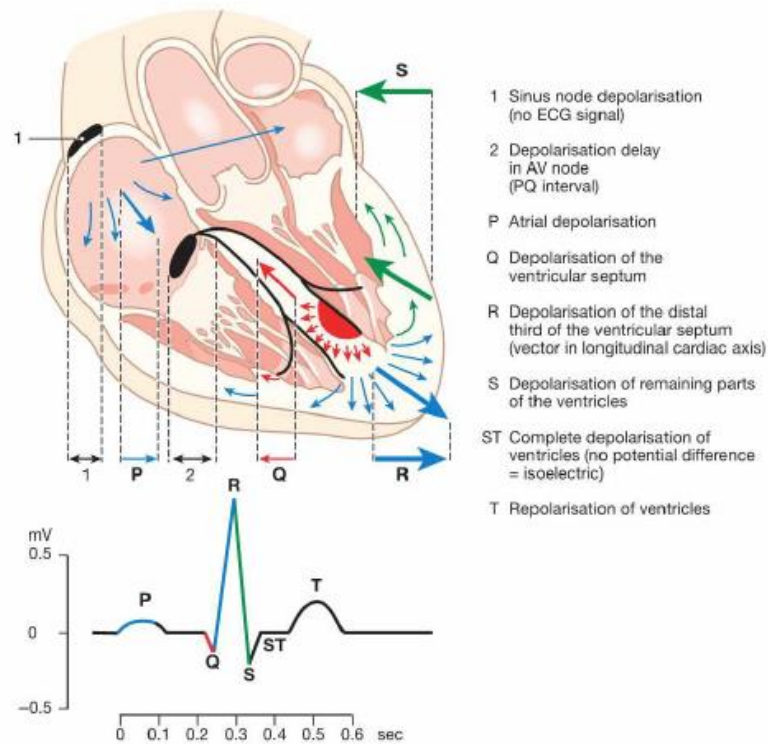
According to Fontana (2018), the electrical conduction system is specified by its three main functions – autonomy, conductivity and irritability. Autonomy stands for independence in generating electric impulses. Each contraction originates within the heart itself independently on the central neural system which can only affect the pace of the impulses, not their creation. Conductivity is responsible for leading the electrical activity resulting in contraction to all myocytes. Irritability signalizes the heart's ability to react only to signals of a certain intensity. The impulses of lower intensity do not create a contraction.

Čihák (2016) says that the fundamental structure of the electrical conduction system is the sinoatrial node (nodus sinoatrialis) which creates electrical impulses and, therefore, defines the heartbeat. It is located in the septum of the right atrium and it is supplied by a branch of the right coronary artery (arteria coronaria dextera). The contraction incentive originates in nodal myocytes (nodus sinoatrialis) and expatriates throughout the right atrium, and through Bachman's Bundle to the left atrium. The electrical impulse stimulates the myocardium of the atria to contract (depolarize) and its conduction is seen on the ECG as the P wave. As the activity spreads throughout the atriums, it travels via internodal traces to the atrioventricular node (see picture 3) (Trojan, 2003).

The atrioventricular node (nodus atrioventricularis) is located between the right atrium and right ventricle in the atrioventricular septum. It is characterised by the atrioventricular delay which is essential for a normal heart function. Without the impulse delay, the atria and ventricles would contract at once without the blood effectively filling the ventricles. This delay is seen on the ECG as the PR segment (Čihák, 2016).

Afterwards, the electric impulse is conducted via the bundle of His (fasciculus atrioventricular) which is split into the right and left Tawara branch in the intraventricular septum (Čihák, 2016). Furthermore, the left Tawara branch is divided between to single bundles which lead the impulse to the left ventricular myocardium (Trojan, 2003). Consequently, the Tawara branches ramify into Purkinje fibres which convey the electric impulse to the working myocardium. According to Biga et al. (2019), the spread of electrical activity through the ventricular myocardium produces the QRS complex on the ECG.

The last event of the cycle is the ventricular repolarisation which restores the resting state. Repolarisation is demonstrated on the ECG by the ST-segment, T and U waves (Yan, 2003).



Picture 3: The electric conduction system of the heart and its ECG projection
(Dalkowski et al, 2011, str. 22)

2.2 Cardiac Cycle

The cardiac cycle describes systole (myocardial contraction) and diastole (myocardial relaxation). Each phase is characterised by volume and pressure changes in chambers. In general, we can differentiate these phases according to the dominant change which can either be pressure change in the ventricles with no significant volume change or in contrary, ventricular volume change with only a small change in pressure (Trojan, 2003). Because fluids flow according to the pressure gradient, it is natural for them to move from the areas with higher pressure to areas with lower pressure (Biga et al., 2019).

Therefore, Trojan (2003) differentiates two phases of systole and two phases of diastole. Systole consists of an isovolumetric contraction and an ejection phase. Similarly, diastole is split into an isovolumetric relaxation and inflow phase. The whole cardiac cycle lasts for approximately 0,83 second (considering the average heartbeat of 72 bpm).

2.2.1 Isovolumetric Contraction

The phase of isovolumetric contraction is the first part of ventricular systole during which the tricuspid and mitral valves close. The semilunar valves (pulmonary and aortic valves) are also closed and the intraventricular pressure rises as the myocardium contracts. The isovolumetric contraction lasts 60 ms (Trojan, 2003).

2.2.2 Ejection Phase

Trojan (2003) claims that when the intraventricular pressure grows higher than the arterial (pulmonary and aortic) pressure, the semilunar valves open and the blood is ejected to pulmonary and systematic circuits. The ventricular pressure reaches its maximum which varies from 120 to 140 mmHg in the left ventricle and from 20 to 30 mmHg in the right ventricle. During the ejection phase, the heart base pulls the ligaments attached to the atria resulting in their expansions and, therefore, faster filling. Whenever the ventricular pressure drops below the value of arterial pressure, the semilunar valves close and systole ends. The ejection phase lasts approximately 200 ms.

2.2.3 Isovolumetric Relaxation

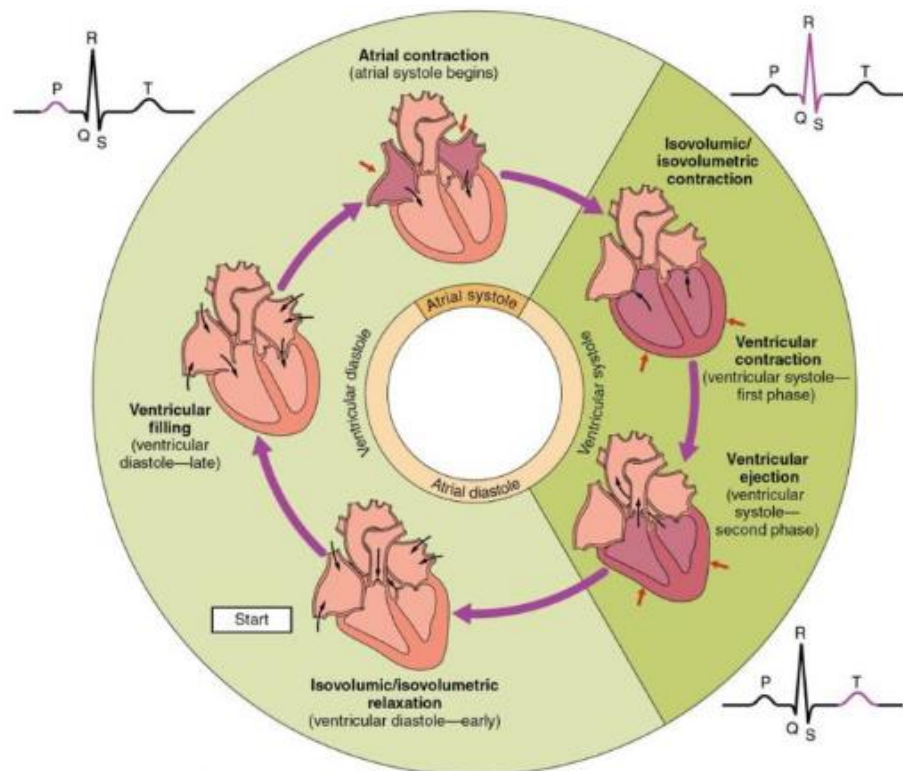
Similar to isovolumetric contraction, the phase of isovolumetric relaxation is only 50 ms long and it starts with all valves closed. It starts with the closure of semilunar valves when the intraventricular pressure reaches the pressure in arteries (described above in 2.4.2 Ejection Phase). Myocardial relaxation results in intraventricular pressure drop to even lower than the pressure value in atria which is when the cuspidal valves open and the blood from the atria flows into the ventricles (Trojan, 2003).

2.2.4 Inflow Phase

At the very beginning of the inflow phase, the intraventricular pressure drops to its lowest, almost reaching 0 mmHg. At the end of diastole, the pressure in the left ventricle rises to its diastolic maximum at around 16 mmHg. The pressure value is an indicator of the left ventricular diastolic function. Its growth indicates pathological changes leading to an increase of rigidity of ventricular wall (Trojan, 2003).

According to Trojan (2003), the inflow phase consists of three consecutive sub-stages, namely: rapid inflow, diastasis, atrial systole. The rapid inflow phase starts immediately after the cuspidal valves open when the blood which was continually filling the atria flows into the ventricles. The blood pressure in both atria and ventricles drops. Diastasis is a phase of a slow blood inflow. The blood coming from the systematic and pulmonary circuit to the atria flows directly into the ventricles, concluding in gradual pressure growth.

The ventricles are normally filled to approx. 70-80% of their capacity as a result of the rapid inflow phase and diastasis (Biga et al., 2019). Atrial systole, as well referred to as the “atrial kick” supplies the rest. The inflow phase is normally from 400 to 500 ms long yet in case of growing heart rate it shortens the most.



Picture 4: The cardiac cycle (Biga et al., 2019, str. 1343).

2.3 Myocardial Infarction

According to Nečas (2007), a myocardial infarction is ischemic necrosis which develops from an obstruction within a coronary artery and lasts for at least 20 to 40 minutes. Most often it is caused by atherosclerotic changes which culminate in a rupture of the atherosclerotic plaque or blockage with a blood clot.

2.3.1 Atherosclerosis

The atherosclerosis is a chronic progressive disease of the vessels characterised by a local accumulation of lipids and other blood components in a vessel wall. It is a chronic long-term disease; it is evolved as an endothelial inflammation with an excessive answer to LDL (low-density lipids). It can be divided into two phases. The lipids cumulate in the vessel walls during the first phase. During the second, final phase, a thin layer made of collagen or elastic fibres is created on top of the lipid layer. Afterwards, the lipid layer is calcified, in later stages it ruptures and bleeds which results in a thrombus creation (Češka et al., 2005).

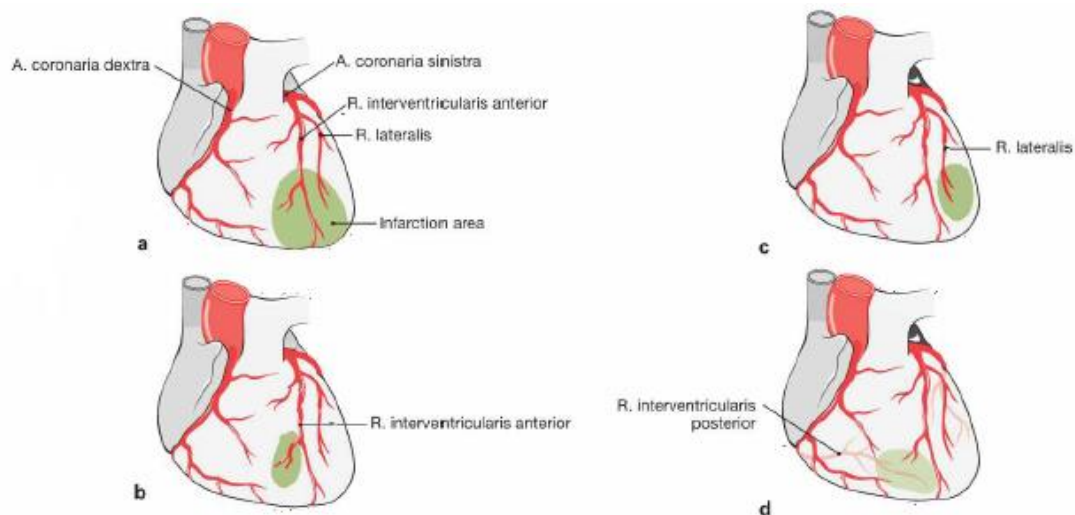
According to Češka et al. (2005), atherosclerosis can be caused by several risk factors from which some are modifiable and some are not. Among others, the most significant ones are namely diabetes, abdominal obesity, insulin resistance, hypertension, smoking, advanced age, family history and gender (male).

2.3.2 Ischemia of the myocardium

The coronary heart disease (also known as the ischemic heart disease) is a whole spectrum of diseases influencing the coronary arteries concluding in reversible or irreversible changes of the myocardium. We differentiate the acute and chronic forms. Among the acute states belongs acute myocardial infarction, unstable angina pectoris and sudden cardiac death. Among the chronic forms, there is for example: the state after myocardial infarction (more than 6 weeks), stable angina pectoris and chronic cardiac failure (Češka, 2010).

As a result of cardiomyocyte hypoxia, metabolic changes of the tissue can lead to their dysfunction and conclude in apoptosis or cell necrosis (in case of myocardial infarction). The accumulation of metabolites such as lactate, serotonin or adenosine, causes an angina pain. The damaged tissue starts an inflammation which results in ligament scarring. The area affected (Picture 5) by ischemia shows kinetic disorders and can lower cardiac output (Nečas, 2007).

According to Nečas (2007), the insufficiency of the left heart function may result in lung hypertension. It can conclude in lung oedema, dyspnoea and progress of cardiac shock. The pressure decrease of the whole system activates the vegetative neural system increases the heartbeat and causes sweating, cold skin and nausea. Mandras and Desai (2019) claim, that the right heart insufficiency or failure is most commonly a result of a left ventricular failure, via pressure and volume overload and it may cause limb oedema and ascites.



Picture 5: An occlusion in an artery leads to ischemia in a specific location of the myocardium (Dalkowski et al., 2011, str. 27)

2.3.3 Classification

Myocardial infarction is usually divided either based on its severity or location. When dividing according to its severity, we recognize transmural and non-transmural infarction. The transmural ischemia involves the full thickness of the myocardium while the non-

transmural ischemia only affects a part of it. According to the changes observed in the ECG, these are clinically called STEMI and NSTEMI.

STEMI is defined by ST-segment elevation in the ECG which is caused by the transmural ischemia and it has a typical ECG (more in chapter 2.5.4) (Foth and Mountford, 2018). NSTEMI is caused by the non-transmural ischemia. The ECG can have various abnormalities, for example, ST-segment depressions or T-wave abnormalities. But we cannot observe ST-segment elevations (Damhoff and Huecker, 2019) on the ECG representation of STEMI. As STEMI leads to greater ischemia, it is considered a more severe form.

When based on its location, we differentiate the following cases (see Figure 1). For a specific position of the mentioned arteries, see Picture 2 (above).

<i>Occluded coronary artery</i>	<i>Location of the infarction</i>	<i>ECG projection</i>
RIA proximal	anterior wall	V1-V6, aVL, I
RIA distal	anteroseptal	V1-V4, aVL, I
Ramus diagonalis	lateral	aVL, I, V5-V7
Ramus posterolateralis	posterolateral	II, III, aVF, V5-V6
RCX	strictly posterior	V7-V9, aVF, III
RCA	inferio-posterior, right ventricle	II, III, aVF, V3r-V6r, V1

Figure 1: Myocardial infarction differentiation based on the location of its occlusion.

The ECG projection describes the ECG lead which shows the pathological changes (Herold, 2015).

2.3.4 Diagnostics

The diagnostics of myocardial infarction overall consists of various medical procedures from which some of them extend beyond the scope of the topic of our bachelor thesis.

Firstly, we focus on the patient's symptoms. According to Mayo Clinic (2018), the symptoms of a heart attack may vary and the patient can feel any or all of them. Among the symptoms belongs a pain in the centre of the chest (can be substituted with an

uncomfortable pressure of squeezing); pain spreading to the shoulders, teeth, jaws, neck, arms (one or both, more usually the left arm) and back; dizziness or fainting; light-headedness; shortness of breath, nausea, indigestion and sweating. The chest pain persists for more than 15 minutes but also does not have to be present at all, therefore it is important to be aware of the other symptoms.

Next step is the ECG evaluation. If we can observe the ECG criteria for STEMI (for example the pathologic ST-segment elevation, new blockage of left bundle branch block), we can diagnose STEMI. In this case, the patient needs to be treated as soon as possible (more in chapter 2.5.5). In other cases, the patient is still suspected of NSTEMI (Foth and Mountfort, 2018).

To confirm or exclude NSTEMI we need to evaluate cardiac troponin level (further mentioned as troponin). Troponin is a biomarker which is measured in blood. Increased troponin blood level signals a heart muscle damage - the more damage there is, the greater the concentration in blood. Increased troponin in blood above certain level diagnoses a myocardial infarction. Therefore, it is increased in both myocardial infarction cases - STEMI and NSTEMI. As mentioned above, the diagnosis of STEMI does not need the evaluation of troponin, because it is clear from the ECG which takes less time. But for NSTEMI diagnosis the troponin level is crucial and determining (Češka, 2010).

2.3.5 Treatment

Treatment of myocardial infarction, as well as its diagnosis, extends beyond the scope of our topic. Its techniques are only briefly described for completeness of the topic.

Initial treatment strategies aim to reduce cardiac ischemia and prevent death. According to the official guidelines issued by the European Resuscitation Council (ACLS Training center, 2018), the airway, breathing, and circulation should be monitored and supported if needed. If the patient's pulse oximetry decreases below 94% or the patient is short of breath, the oxygen should be administered. Obtaining a 12-lead ECG is essential for further management of the patient (ACLS Training center, 2018).

It should be considered rather early in the care of the patient to which medical facility they will be transported. If there is a facility prepared for a percutaneous coronary intervention (PCI, explained below) within the range of 90 minutes and the patient's

condition allows it, the patient with STEMI should always be transported to such facility (ACLS Training center, 2018). According to Almawiri et al. (2017), direct transport to a catheterisation laboratory significantly reduces the mortality of such patients.

Morphin, Oxygen, nitrates and aspirin (MONA) are administered if there is an initial concern for the acute coronary syndrome (ACS). The acute coronary syndrome is a general term for the acute forms of ischemic heart disease – acute myocardial infarction and angina pectoris (Češka, 2010). MONA can be administered prior to a definitive diagnosis. Anticoagulation treatment should be initiated in patients where acute myocardial infarction is highly likely. If PCI is not possible within the stated range, fibrinolytic therapy should be initiated within 30 minutes of patient arrival at the hospital (Damhoff and Huecker, 2019).

According to Damhoff and Huecker (2019), the treatment of NSTEMI patients is highly dependant on the patient's state. Both pharmacological and invasive methods can be employed.

The percutaneous coronary intervention (PCI) starts with angiocardiology, which is a medical imaging technique. It is used to visualise the inside of the coronary arteries by injecting an iodine-based radio-opaque contrast. The skin is locally anaesthetised and a catheter is threaded into the femoral or radial artery. The fluorescein angiography is used to display the coronary occlusion. As soon as the catheter is in place, PCI can be performed (Navrátil et al., 2005).

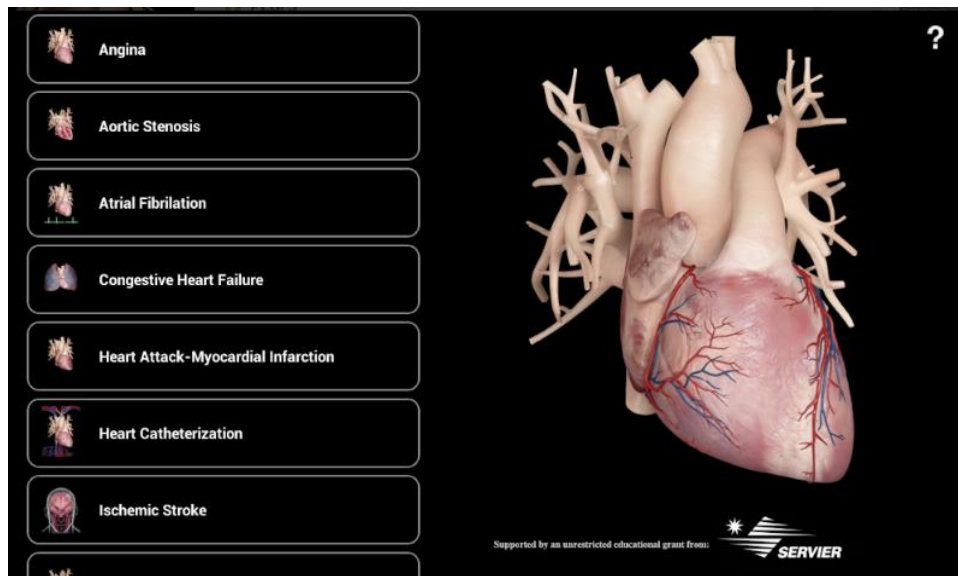
PCI is an invasive therapeutic method used for stenosis dilating. This is done by using a special balloon catheter which inflates the stenosis. The dilatation can be followed by stent implantation. The indications for PCI is angina pectoris (both stable and unstable), acute myocardial infarction and the stenosis of an aortocoronary bypass. Among the contraindications there are for example an unstable state of the patient, bleeding, haemodynamically insignificant stenosis or stenosis which is too excessive (Zeman, 2006).

2.4 Mobile Applications: A State-of-the-Art Summary

With the expansion of smart mobile phones and mobile internet, it is becoming common for a student to use various approaches to education. One of the easiest ways is downloading a free mobile application that is both informative and interactive therefore it makes studying more interesting and pleasurable. Currently, there are many Android applications available on Google Play which focus on anatomy or/and physiology of the human body. Unfortunately, there is only a few applications aimed at the myocardial infarction or pathophysiological changes of the heart in general.

2.4.1 Cardiological

Cardiological was developed by 3D4Medical in collaboration with Stanford University School of Medicine. Its aim is to introduce various heart (or heart-related) diseases to the user (Les Laboratories Servier, 2017). It includes an animation of macroscopic organs and microscopic cells joint together into one video. The used models are illustrative but there are not any descriptions neither of the organ itself nor the pathophysiological process. Its target audience is healthcare personnel yet it is an educative application, therefore, we perceive it as a missing aspect. Specifically, the video of myocardial infarction is not very accurate in the post-infarction tissue and function changes as the new tissue is hardly visible and the kinetic function of the heart is completely omitted. The user interface is simple and neat with basic fade transitions between the views. Overall, it can be a good study help for users who already have an awareness of the processes happening during the disease but have problems with visualisation. The laity would probably appreciate at least basic information.

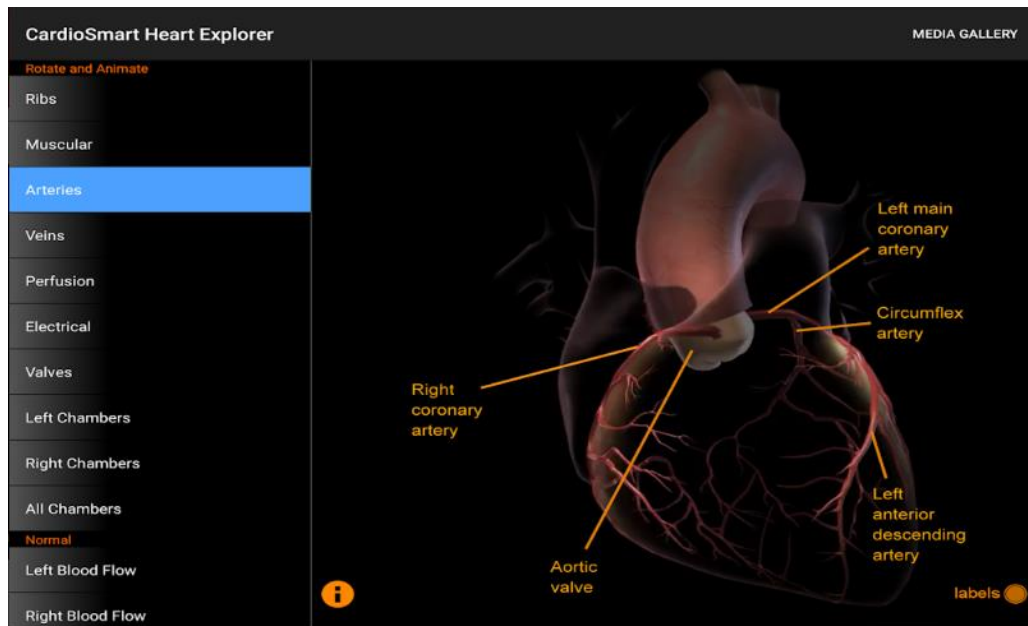


Picture 6: The menu screenshot of Cardiological (Les Laboratoires Servier, 2017).

2.4.2 CardioSmart Heart Explorer

An application named CardioSmart Heart Explorer was created by the American College of Cardiology Foundation (2018). It offers a wide range of options to its user, for example, the user can see the animations of various organs and tissues (ribs, muscles, arteries, veins, chambers, etc.) as well as some heart conditions (heart attack, mitral valve prolapse, fibrillation).

The graphics of this application was not exactly unified throughout the whole application. Some models were very well done (arteries) while others (chambers) did not seem that accurate. What we perceived as the main problem was the overall user experience. Specifically, the controllability was not handled well, it was difficult to switch between the fragments and they even sometimes changed while trying to rotate the models. Also, the animation was only playing in one specific position of the model, meaning if the model was rotated, the user was not able to see the animation. A great advantage, on the other hand, were the descriptions of each organ and action happening. The descriptions could have been more educational though as they only described the obvious processes and structures.

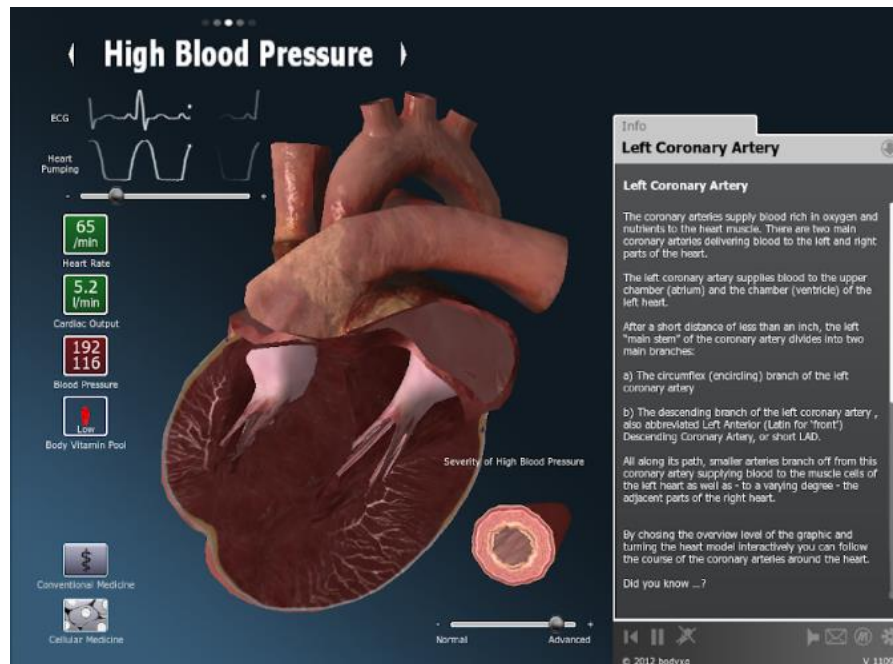


Picture 7: The screenshot of CardioSmart Heart Explorer. The picture of a heart with its arteries (American College of Cardiology Foundation, 2018).

2.4.3 BodyXQ Heart

The application BodyXQ Heart allows its user to explore the human heart. It allows the user to view 5 states which are – healthy heart, arteriosclerosis, high blood pressure, heart failure and arrhythmia. The first three conditions are offered in one mode only while the last two offer three different views, including an overview of the heart, section of a heart and a microscopic view (bodyxq, 2014).

The user can see several vital functions on the screen and see how their values change according to the user input. The user can change the heart rate frequency as well as they can adjust the motion speed. The application also has an education window which provides the user with information on the visible processes. While being probably the best available application in terms of user experience and interactivity, it, unfortunately, provides the user with inaccurate information (for example when speeding up the heart rate, the user can hear irregular sounds indicating extrasystoles or even arrhythmia). Also, the presented models were not professionally designed and they look very primitive (see Picture 8).



Picture 8: Screenshot of the healthy heart within the BodyXQ Heart application (bodyxq, 2014).

2.4.4 Summary

When investigating the-state-of-art of mobile applications focusing on visualization and education about myocardial infarction, we came to identify the main missing aspects. They are as follows.

Firstly, although 3D visualization technology is currently very advanced, it is almost impossible to find applications which would visualize myocardial infarction with professionally naturally-looking designed graphics.

Secondly, the information provided by applications is often very brief, sometimes even incorrect.

Lastly, the user experience is, in general, very poor. The user usually does not have the ability to interact with the application to an extent greater than only selecting an item from the menu.

3 Practical Part

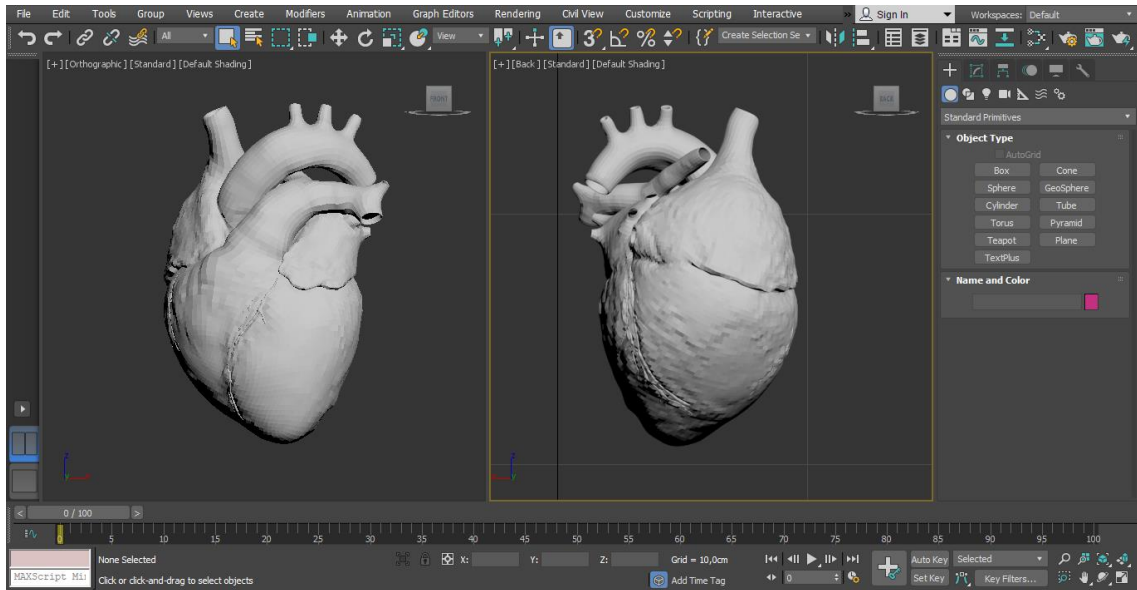
The practical part of this bachelor thesis focuses on developing a prototype of a mobile application for educational purposes on the topic of myocardial infarction. Firstly, we create an overview of existing mobile applications with the same or very similar topic and identify their benefits and disadvantages. Further, we analyse spaces for improvement. Secondly, with a group of target users, we discuss their main needs and thus identify the objectives of our application. Thirdly, we focus on creating the animations used within the application. And lastly, we create a concept of our application and develop the prototype which we also test with our target users.

3.1 The model

3.1.1 Original model

The original model (see in Picture 9) was bought from the TurboSquid portal (ANON, 2019). The decision to buy a 3D model as a starting point for further adjustments was supported by the Faculty of Health Studies. 3D modelling is not an easy discipline, thus creating a completely new realistic model would highly exceed the extent of the bachelor thesis.

We chose a model created by DisneyTD as it was the closest available model to a physiological heart both in shape and texture. The original model was build in Maya 2018, it had 38379 polygons and it also came with the muscle-like texture which can be seen in the final videos. It was awarded the CheckMate Pro standard which says that the original model either meets or exceeds professional production needs. Therefore, it opens without errors and looks precisely like the image presented on the website (ANON, 2019).



Picture 9: The original model. When firstly opened, its pivot needed to be recentered. In addition, the texture only came with the model, it was not implemented.

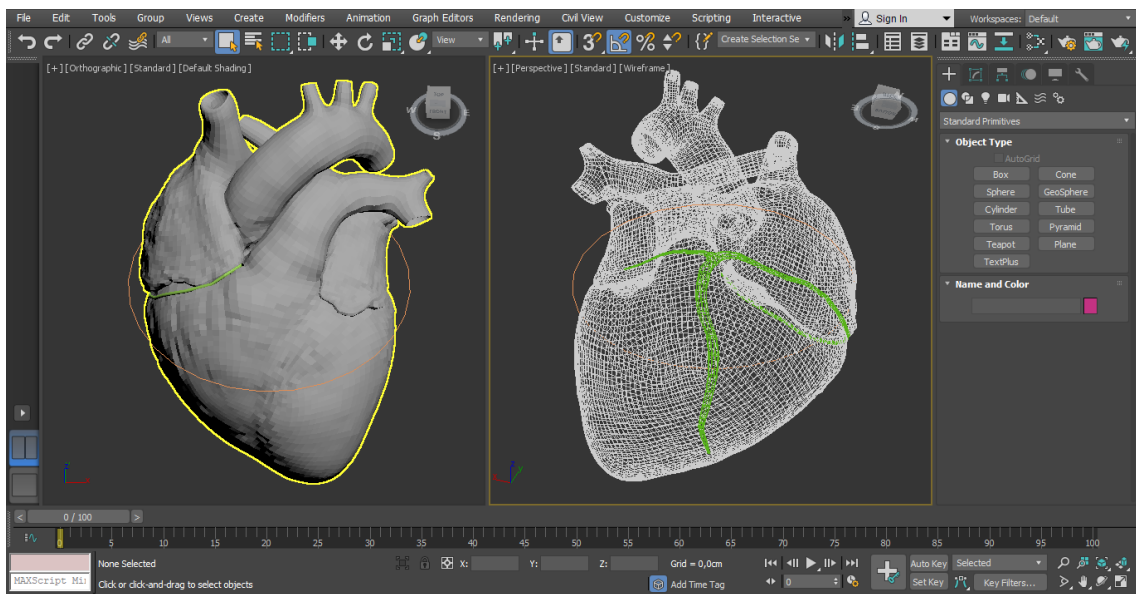
3.1.2 Remodelling

As the original model was only a shell of a heart without any further add-ons (veins, arteries, nerves, etc.) our first task was to create the coronary arteries. The coronary arteries are the fundamental vessels in case of myocardial infarction. We decided not to model the coronary veins as they do not supply the heart muscle with oxygenated blood, therefore they are not essential for the visualisation. In fact, they would probably only confuse the user. We decided to model two main arteries, the arteria coronaria dextra and arteria coronaria sinistra. When modelling the right coronary artery, we also created the ramus marginalis dexter, the ramus circumflexus arteriae coronariae sinistralae and the ramus posterior ventriculi sinistri. Our left coronary artery branches out into the ramus interventricularis anterior and the ramus interventricularis posterior arteriae coronariae dextrae. The decision to model only those mentioned arteries and branches was based on their size and the area they supply with blood (Picture 2, Picture 5).

We chose 3ds Max 2019 (student version) as our primary application for model adjusting and animating because of previous experience and knowledge.

Both arteries were created with a cylinder as a starting object. The cylinder was firstly converted into edit poly. Then its caps were removed and it was extruded along a newly created spline (see Picture 10). We used a circle whose diameter was similar to the

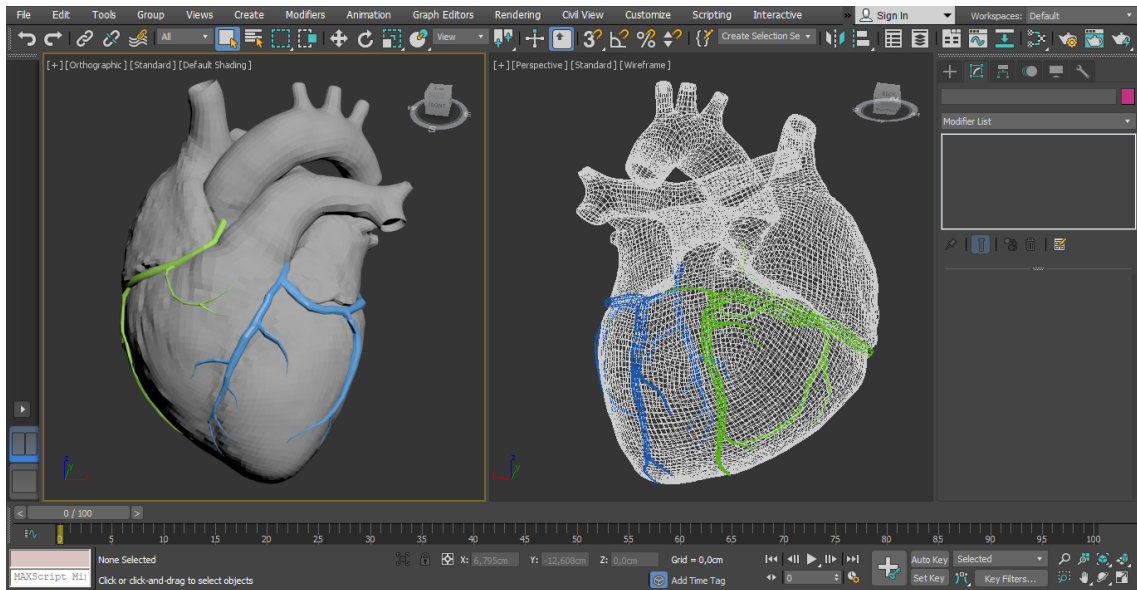
diameter of the heart. As the cylinder extruded, we removed approximately two-fifths of the object and repositioned the newly created skeleton of the right coronary artery. The artery was rescaled in order to be properly visible and correspond with the real size of a coronary artery. As soon as the size was as accurate as possible and the artery was lying on the heart, small adjustments needed to be done. Each segment (10 sided cylinder) had to be accordingly allocated, enlarged or reduced and rotated in order to reach a natural look. Also, distal segments were slightly rescaled to represent a natural narrowing of the artery.



Picture 10: The first steps in modelling the right coronary artery. The orange circle (visible in both viewports) served as an auxiliary spline along which were the first segments of each artery extruded.

The branches were created by adding extra segments within the segment in the intended area. In order to assure a smooth transition from the artery to the ramus, we created from 4 to 6 additional segments (depending on the size of the resulting branch). A selection of 4 or 6 polygons was deleted and the newly originated edge served as a beginning of the new branch. Firstly, the edge was manually smoothened by moving its vertices and using scaling and rotation. Finally, new segments of the new branch were created by using the move tool with shortcut key SHIFT. It was essential to follow the surface of the heart in order to achieve a natural look. Similar to the main artery branch, the segments were distally minimized (scaled). The same procedure was applied when creating the second artery.

In the end, on top of all the objects was placed the TurboSmooth modifier with two iterations to ensure smoothness of the surfaces. The overall number of polygons increases depending on the number of iterations set within the TurboSmooth modifier. Two iterations multiply the polygon count 16 times resulting in approximately 240 thousand polygons of the heart (arteries were not attached). In the case of attached arteries, the count would nearly double. For performance reasons, the TurboSmooth modifier was disabled for most of the time (until the video export).



Picture 11: Right (green) and left (blue) coronary arteries built and placed on top of the heart. Different colours prompt that the arteries and the heart are kept as three separate objects.

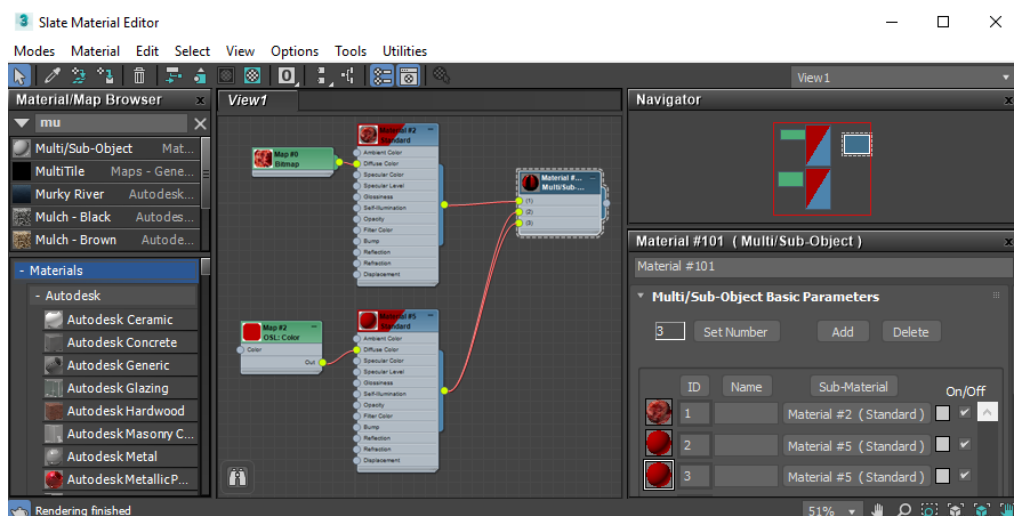
3.1.3 Material

The texture of our model was bought with the original model described in chapter 3.1.1. The texture was in a tiff format and it was a detailed map of a heart (see Picture 12). There were several coronary vessels visible as well as fat tissue which naturally occurs on the human heart. When deciding which colour would be most suitable for the arteries, we aimed for a natural look (therefore we chose red) yet it was important that the arteries did not blend with their background. Using the texture would not be appropriate because of the variable shape of the arteries.



Picture 12: The texture of our heart. Several vessels are visible as well as fat tissue which naturally occurs on the heart.

In order to apply materials (both texture and colour) to our model, we used the Slate Material Editor in 3ds Max (see Picture 13). As we needed to connect the arteries which were until this moment kept as separate objects to the heart for simplifying the animation, we assigned them different material IDs. Specifically, the heart was assigned with the ID 1 and the right and left coronary arteries were assigned 2 and 3, respectively. The heart texture file was inserted in the editor; for colouring the arteries, we used the general map ColorMap where we selected the colour from a palette. Both maps were then connected to Diffuse colour and merged together with the Multi/Sub-Object Material. We set the ID values within the Multi/Sub-Object Material parameters and linked the output with our model.

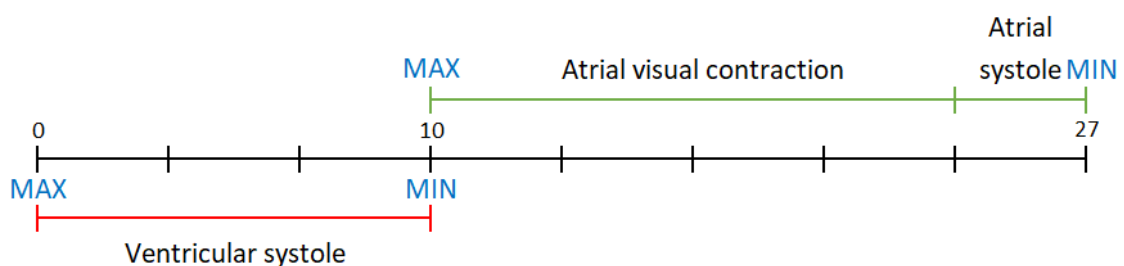


Picture 13: Slate Material Editor in 3ds Max. It shows the material setting which was used for implementing the materials (texture and colour) to our model.

3.1.4 Animation

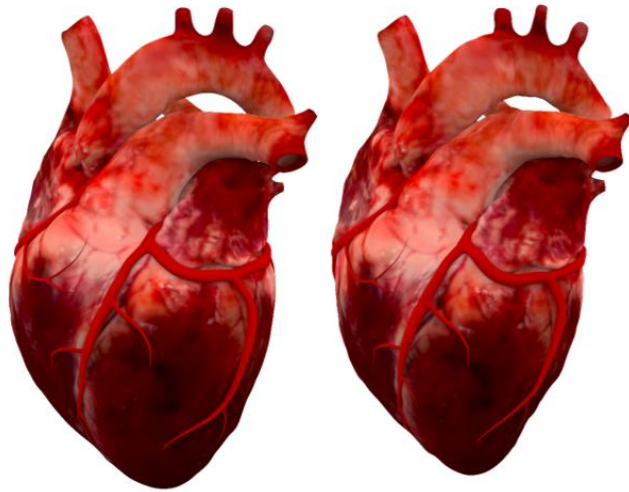
Before animating the atria and ventricles, deep apprehension of the cardiac cycle was essential in order to create a natural animation. The most important aspects for the animation process were the volume changes within the chambers and their duration. For simplicity, we decided not to take into consideration the isovolumetric phases of the cycle as their duration is, according to Trojan (2003), very short (50-60 ms). The user would not even be able to spot them.

We made animation according to Biga et al. (2019) and his description of the cardiac cycle together with the Innere Medizin Krankenhaus Sulzbach (2015) and simplified for the needs of the animation. According to Biga et al., the atrial systole lasts 100 ms and the ventricular systole lasts 270 ms. The atrial systole happens at the end of the ventricular diastole. On the other hand, according to the Innere Medizin Krankenhaus Sulzbach (2015), we can see that the atria visually contract prior to their systole. In order to simplify the animation, we decided not to include the atrial kick. We based the animation on a ratio of atrial to ventricular systole 5:3 (Picture 14). The atria acquire the highest volume at the end of ventricular systole when the ventricles are at their lowest volume. Similarly, the atria are at their minimal volume at the end of atrial systole which is as well the beginning of ventricular systole and, therefore, the ventricles acquire their highest volume.

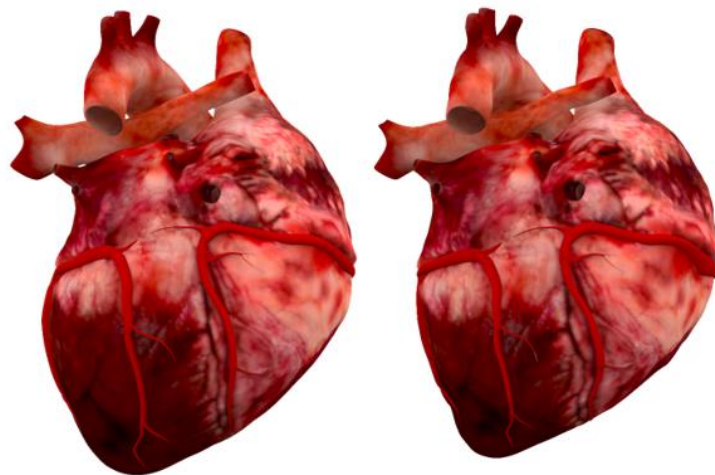


Picture 14: Our scheme of the simplified animation – The blue labels describe the atrial and ventricular volume during each phase while the green and red marks illustrate the visualisation of contraction. The numbers represent the frames.

We decided to create the animation of the heart itself in two key frames. The first frame was the end of atrial systole and the beginning of ventricular systole. The second frame was the end of ventricular systole and the beginning of atrial visual contraction (Picture 15, Picture 16).



Picture 15: The frontal view of the healthy heart animation. The left picture is the frame 0 and 27 (end of atrial systole, beginning of ventricular diastole) and the right picture is the frame 10 (beginning of the atrial visual contraction, end of ventricular systole).



Picture 16: The lateral view of the healthy heart animation. The left picture is the frame 0 and 27 and the right picture is the frame 10 (similarly to the previous picture).

In addition to the healthy heart animation, we also created a camera animation for the audience to see the heart rotate. We used the target camera and let it follow a trajectory of a circular spline centred to the heart. We animated the camera separately with two frames, both being the starting point of the camera. Each of the frames was placed to the beginning and the end of the animation of the heart, therefore to frames number 0 and number 363 respectively.

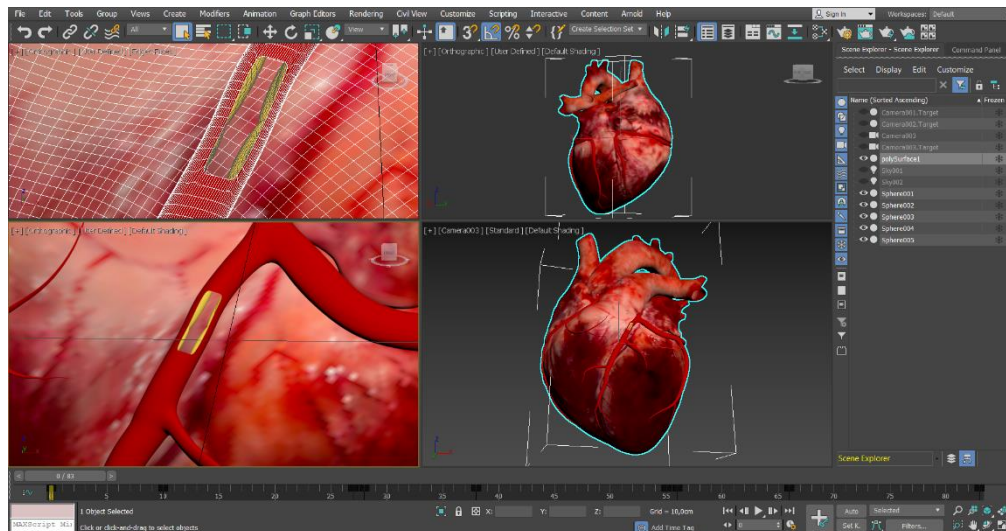
In 3ds Max 2019, we made the animation using the autokey method. Assuming a healthy heart and a typical rate of 72 beats per minute, each cardiac cycle, or heartbeat, takes 0.83 seconds to complete the cycle (Trojan, 2003). But in order to make the animation of the healthy heartbeat properly visibly, we slowed the frequency down to 65 beats per minute. Our animation consists of 364 frames in total and runs at the speed of 30 frames per second.

3.1.5 Myocardial infarction

According to Dostál (2007), the anteroseptal ST-elevation myocardial infarction is the most frequent type of myocardial infarction, therefore, we chose it for the visualisation of myocardial infarction. We created several separate animations of the myocardial infarction process. We chose this approach due to the length of the animation. If creating only one animation, its length could be even several minutes. In addition, the final file would be too large for loading within the application. Instead, we split the animation into five steps with additional comments for a clear explanation of the pathophysiological processes. We also decided not to move the camera this time as it would only prolong the animation, thus the length of the video, yet the user would not see anything from the back.

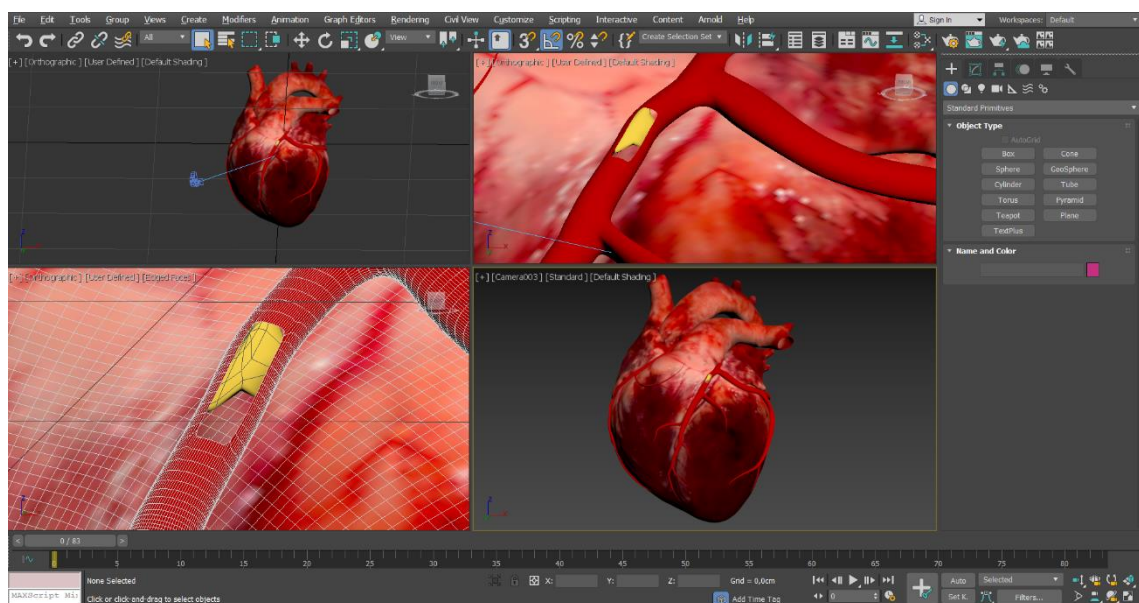
Firstly, we show the healthy heart and its normal function (beating at the frequency of 65 beats per minute). That animation was exported from the prepared animation of a healthy heart.

The second animation shows the atherosclerotic plaque built up in the coronary artery, namely in the ramus interventricularis anterior of the arteria coronaria sinistra. When adjusting the animation, we removed a part of the artery to ensure the user's ability to see inside of the artery (as can be seen in Picture 17). In the artery, there are yellow spheres which represent the plaque. We adjusted the spheres (reshaped, rotated and rescaled) in order to fit inside of the artery yet not fill it completely as the blood should still be flowing. We also changed the position of the plaque in each frame of the animation to ensure a smooth transition of the frames during the contraction of the heart which naturally moves the arteries as well.



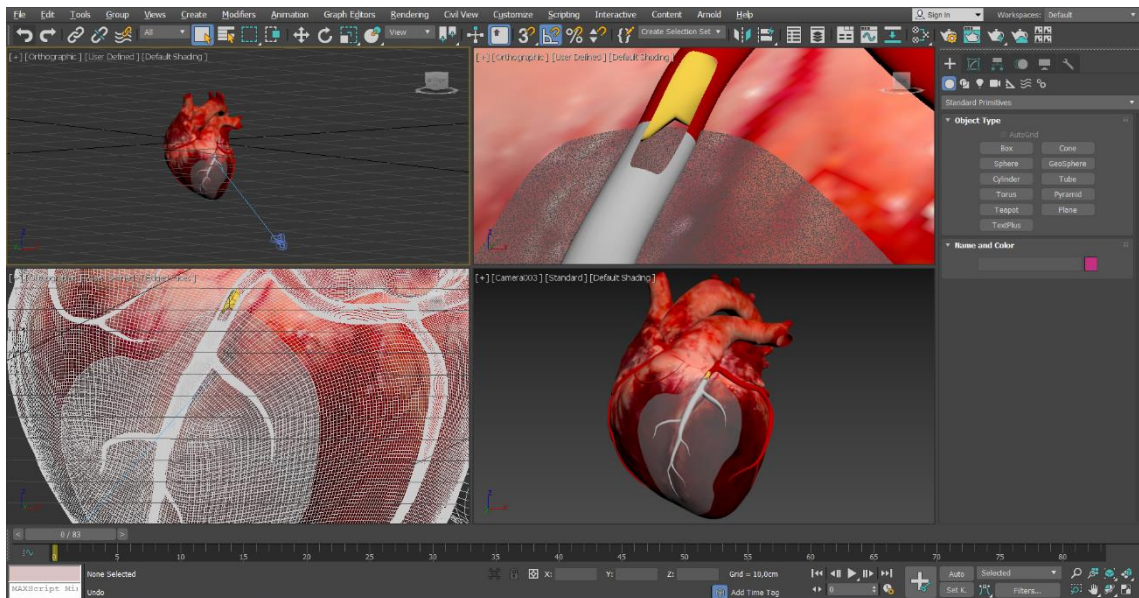
Picture 17: Detail of the model with the atherosclerotic plaque built up in the RIA. The left top and bottom views show the detail of the plaque, the right top view displays an overview and the right bottom view is the camera view.

The third animation (Picture 18) represents the obstruction of the ramus interventricularis anterior. The plaque's burst resulted in a blockage of the artery, approximately 1 cm distally from the split of the left coronary artery. We added more yellow spheres in the resection of the ramus and adjusted their position according to the movement of the ventricles. The user can see that the intersection of the ramus is cluttered.



Picture 18: An overview of the third model of myocardial infarction – the right bottom view shows the camera view, the other views show the atherosclerotic occlusion.

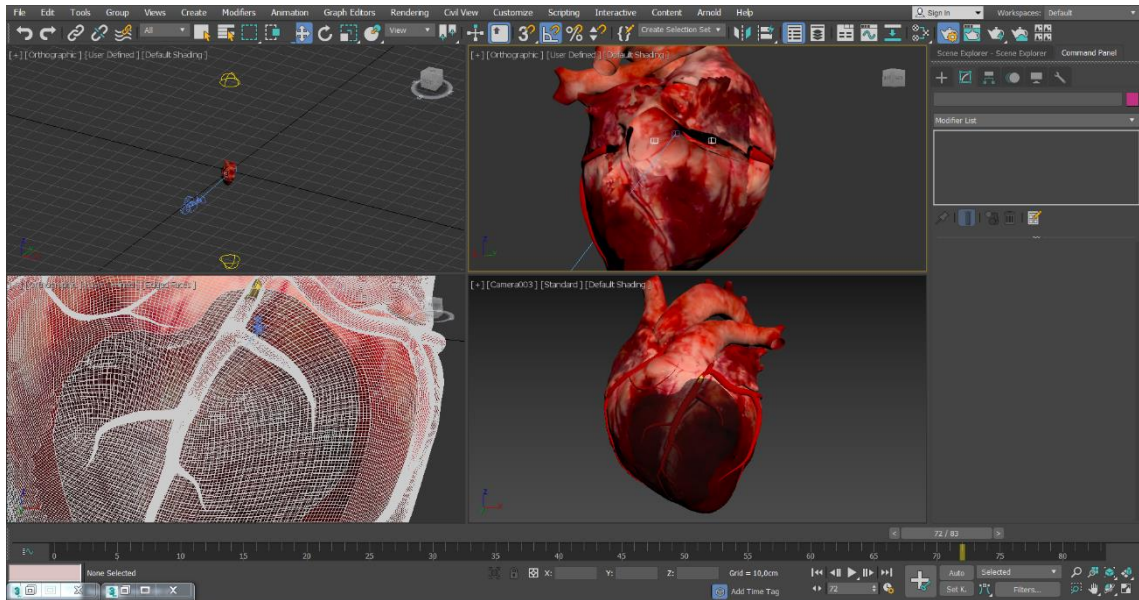
The area affected by ischemia can be seen in the fourth animation where it is highlighted with a light grey colour (Picture 19). The user can still see the obstructed ramus in the intersection and the heart is still normally beating. The purpose of this animation is to demonstrate the seriousness of myocardial infarction as well as the size of the affected area. The extent of the area was inspired by Paulsen and Waschke (2011). We created the grey highlight by copying the polygons of the heart that were intended to be affected. We had to manually smoothen the edges of the plane by moving the edge vertices. Subsequently, we placed the whole plane on top of the heart and modified it in each frame according to the movement of the ventricles. Finally, we added a material to the plane which was a colour texture with set opacity. The opacity level was chosen so that the area beneath the plane was still somehow visible yet the audience should be primarily attracted to the highlighted area.



Picture 19: The myocardial ischemia – The left bottom and right top views show the detail of the ischemic plane. The right bottom view is the camera view

The fifth animation focuses on the necrotic tissue (Picture 20). According to Nečas (2007), the necrotic tissue (for example after myocardial infarction) embodies kinetic malfunction. In the animation, it is represented by a static black highlight which is in place of the grey highlighted area from the fourth video. In 3ds Max 2019, the model remained the same as it was in the third step but we deleted the ischemic polygons. Instead, we slightly minimised the model of the healthy heart (with normal heartbeat animation) and inserted it inside of our model. We identified the keyframe with the end of ventricular systole (therefore with the minimal ventricular volume) and removed the

rest of the keyframes. Then, we selected the ventricular polygons which could be seen through the newly incurred resection in place of the necrotic tissue and deleted the rest of the inner heart. The aim was to delete all the polygons that were not visible as it lowers the computational demand. The necrotised tissue was then coloured with black colour texture.



Picture 20: The necrosis – Similarly to ischemia, there is a plane which signals the necrosis. In the top right view is a detail of the back of the heart which was deleted due to the graphics performance difficulties.

3.1.6 Model testing

Our first aim was to implement the full animated models in the mobile application in order to ensure full interactivity. When firstly testing the implementation of a static model in a single screen application, we became concerned about the loading speed. A file of the original static heart model (without the remodelled arteries) which was approximately 64 megabytes large took 58-65 seconds to build within the application. The reason was that the model was rendered within the application. Our simplest model consisted of almost 40 thousand polygons, therefore as the polygon number grows with the difficulty the model, we expected the rendering time grow. Model testing was done on Lenovo TAB3 8.

To reduce the loading time, we decided on the video export approach, transferring the rendering phase before implementing in our application. Even though the rendering time of the video is much longer than one minute, by exporting the video we significantly reduced the file size. As a result, instead of having to load a model worth of 64 megabytes, we load a file of a size under 3 megabytes. In addition, this approach is highly user-friendly as the user does not download so much data in his mobile internal storage.

3.1.7 Video export

When exporting the final video, several things needed to be taken into consideration. It was the renderer, the quality, the dimensions and the format of the video, proper visibility of the model and its animation (its placement within the camera view) and the lightning (thus the visibility of the model and its texture).

In terms of the renderer, we chose the Quicksilver Hardware Renderer. Our decision was based on its rendering speed and characteristics. It is in general very quick, especially if it is needed to render the same or very similar view several times which was exactly our case (the keyframes of our animations could be considered almost identical). In addition, it works well with transparent surfaces which was essential for our myocardial infarction videos.

As the output format of the video, we chose HDTV video with 1920 pixels in width and 1080 pixels in height. We aimed to get an excellent resolution so that we could provide our audience with a quality video. The output format was set to be .avi as it is a widespread video format and it is easy to work with (converting, cutting). Due to the high-resolution output settings, the rendering time was around 2,5 hours for the animation of the healthy heart, and approx. 20 to 25 minutes for the myocardial infarction videos.

Before inserting in the application, all videos were reformatted to the mp4 format using an online video converter. The primary video size was 144 megabytes in case of the healthy heart animation (full length, using camera rotation) and varied between 42 to 52 megabytes in case of the shorter infarction videos. Loading such huge files on the user's device would be highly inefficient therefore we converted them to mp4. After the conversion, the size of the files was up to 1,5 megabytes. Due to the video format (proportions), we cropped the background of the video.

3.2 Mobile Application

The goal of the bachelor thesis was to create a prototype of a mobile application which could be used for educational purposes on the topic of myocardial infarction. We chose Android as the target platform because of several reasons, which are:

- number of users,
- user demography,
- programming language,
- price.

Firstly, the number of users and user demography are very closely related. The Android operation system is globally more widely used than iOS. iOS is more popular within the Western countries (North America, Western Europe) and Australia while Android is the leading platform in Central and Eastern Europe, South America, Africa and Asia. Secondly, Android applications can be written in either Kotlin or Java. Due to our previous experience with Java, choosing Android was a natural decision. And lastly, publishing an Android application on Google Play with the single payment of 25 USD is significantly cheaper to publish on App Store (iOS) with its 99 USD per year (R., 2018).

3.2.1 Application Concept

When creating the first concept of your application, we needed to decide about its functionality and the user experience. Since it is a prototype of an educational application, both of these aspects were decided based on ideas and feedback from a group of target users. In the future, the application can be used by the following groups for the mentioned reasons:

- laic audience – understanding myocardial infarction and its effect on a heart, learning about the symptoms and first aid;

- medical students – deepening knowledge about the processes happening during myocardial infarction, diagnosis and treatment of various types of myocardial infarction;
- healthcare personnel – educating their patients in an understandable way by showing them “their” type of infarction and its effect, and discussing the consequences of such condition.

The group of target users was composed of 16 people; the structure of the group can be seen below in Figure 2.

<i>Target group</i>	<i>Number of people</i>	<i>Age</i>
laic audience	5	18 - 65
medical/healthcare students	7	19 - 25
healthcare personnel	3	27 - 35

Figure 2: The structure of our group of target users

We focused on a qualitative assessment rather than a quantitative one as our aim was to develop a prototype which proves the possibility of creating such an application. It was more beneficial to obtain quality input and constructive feedback than gaining a wide range of data. The quantitative assessment would be important in later phases of the application development, for example when focusing on the user experience and interface design.

The discussion about the possibilities of the application resulted in three most important functions. Firstly, the application should visualize an animation of a healthy beating heart which should be reasonably anatomically and physiologically correct. Secondly, there should be an animation of myocardial infarction with description; it should show the obstruction in an artery and the affected area; the consequences of the infarction should be clearly visible. Lastly, the application should contain a quiz section which would allow the users to practise their knowledge.

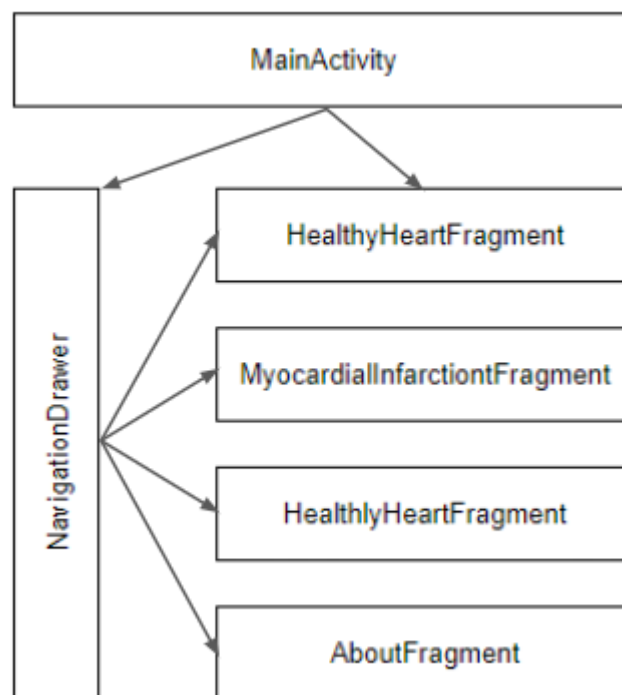
With regards to the user interface, the application was said to be simple yet interactive. It should contain as many animations as possible and it should perform well on various devices (it should not be highly dependent on the user’s device in terms of the capacity, processor or graphics). It should be easy to switch between the screens (healthy heart animation, myocardial infarction animation, quiz) and the application should maintain a unified style across all the screens.

3.2.2 Application structure

The application has a simple hierarchy with MainActivity being the parent to four fragments. The fragments are:

- Healthy Heart Fragment,
- Myocardial Infarction Fragment,
- First Aid Fragment,
- About Fragment.

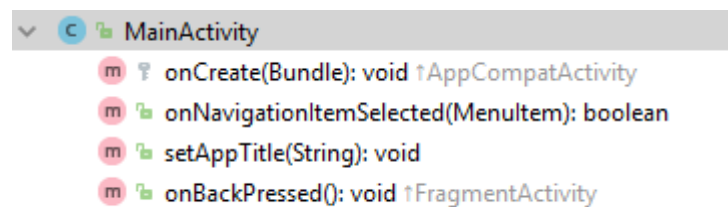
Regarding the user flow, the MainActivity opens the HealthyHeartFragment on startup. The next step would be to open the navigation drawer and choose the desired fragment. The navigation drawer can be opened from every fragment allowing the users to easily switch between what they would like to learn. The scheme of the application can be seen in Picture 21.



Picture 21: Our application structure. The MainActivity is the parent of the four fragments which can be opened from the NavigationDrawer.

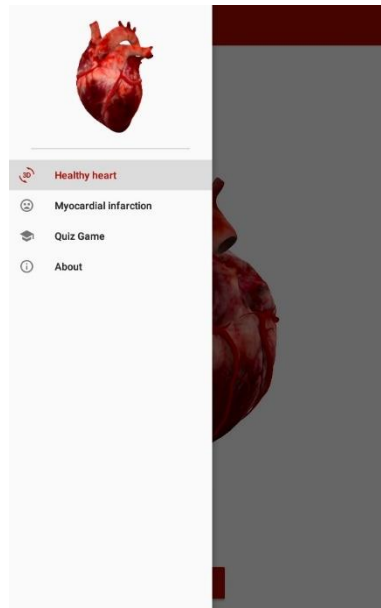
3.2.2.1 Main Activity

The Main Activity consists of four methods as can be seen on Picture 22. It initializes the application with the `onCreate` method which, as mentioned above, sets up the `HealthyHeartFragment` as a startup view. The `onNavigationItemSelected` method consists of a switch-case which opens the fragments according to the user's selection in the menu (navigation drawer). The purpose of the `setAppTitle` method is to change the title displayed in the toolbar based on the current fragment. The `onBackPressed` method handles pressing the back button on the user's device which only lets the user close the navigation drawer if opened.



Picture 22: The structure of our MainActivity showing the main four methods

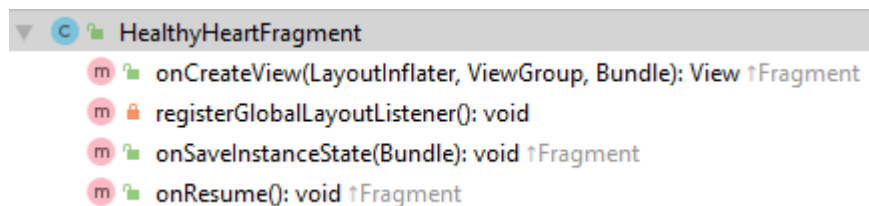
The Main Activity also sets up the customized toolbar which was included in the `activity_main.xml`. We chose our own toolbar over the default action bar because of its extended options in terms of customization. The `FrameLayout` is used as a fragment container which we call from the Main Activity when opening or replacing the fragments. The `NavigationView` implements the menu layout which is separately designed in the `navigation_layout.xml` file and `navigation_drawer.xml`.



Picture 23: The visualization of the Main Activity layout. The parent layout is the DrawerLayout which represents the menu drawer. Also the included toolbar is visible in the upper part of the picture.

3.2.2.2 Healthy Heart Fragment

The HealthyHeartFragment extends the Fragment class and is called on the application startup. It inflates the view designed in the fragment_healthy_heart.xml within the onCreateView method (the component structure can be seen below in picture 25).



Picture 24: The hierarchy of methods in the HealthyHeartFragment

The main purpose of this fragment is to show the user the animation of a healthy beating heart. This is done by displaying the VideoView which opens the previously exported video (see section 3.2.5 Video export for more details). We used the following code for linking the VideoView with the resource file:

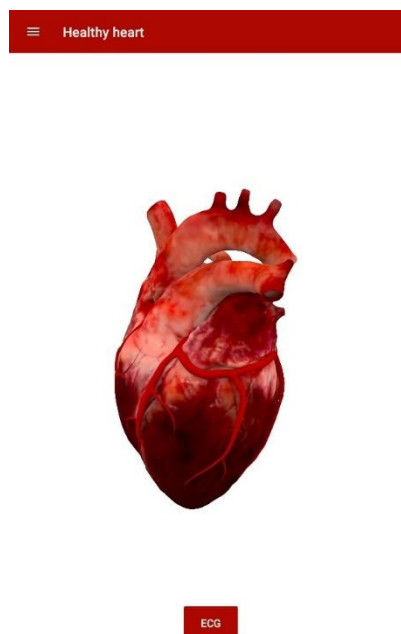
```

mVideoView = view.findViewById(R.id.healthy_video);
String videoPath = "android.resource://com.janastarkova.bakalarka/" +
R.raw.bprender;
Uri uri = Uri.parse(videoPath);
mVideoView.setVideoURI(uri);

```

The registerGlobalLayoutListener method was implemented together with the Media Player for better controllability of the animation video. The video is looping by default and it allows the user to pause or resume it with a single click on the video. The onSaveInstanceState and onResume methods were used for managing the fragment throughout its lifecycle (specifically, for resuming the video after the application has been called from the background).

We chose the RelativeLayout as the parent layout for this fragment. The main components are VideoView, a button and an ImageView (as can be seen on the following Picture 25). The VideoView is linked to a video file saved in the resource folder. The button is used for showing the model ECG. The button has a onClickListener which changes the visibility of the ImageView. When displaying the ECG (img_normal_ecg), the ImageView replaces the VideoView by exchanging their visibilities.



Picture 25: The structure of the Healthy Heart Fragment layout. It shows the parent layout (RelativeLayout) and its main components

3.2.2.3 Myocardial Infarction Fragment

The purpose of the Myocardial Infarction Fragment is to give the user an overview of pathophysiological changes on the heart during the acute myocardial infarction. We decided to split the process into five separate steps which are:

- i. healthy heartbeat,
- ii. the building of the atherosclerotic plaque,
- iii. the occlusion of an artery (RIA),
- iv. visualization of the area affected by ischemia,
- v. visualization of the necrotic tissue.

For displaying the first video (short animation of the healthy beating heart with a static view), we open it from the resource folder similarly to the way in the healthy heart fragment. For displaying the following videos, the user clicks on the next button (btn_next) which increments the btnClicked by one. In case of displaying the previous video, the user clicks on the back button (btn_back) which decrements the mentioned variable. This was done by the following piece of code:

```
btn_back = view.findViewById(R.id.btn_back);
btn_next = view.findViewById(R.id.btn_next);

btn_back.setOnClickListener(new View.OnClickListener() {
    @Override
    public void onClick(View v) {
        btnClicked--;
        if(btn_next.getVisibility() == View.INVISIBLE){
            btn_next.setVisibility(View.VISIBLE);
        }
        videoAndTextChange();
    }
});

btn_next.setOnClickListener(new View.OnClickListener() {
    @Override
    public void onClick(View v) {
        btnClicked++;
        videoAndTextChange();
    }
});
```

```

    }
});

```

When clicking on the buttons, the visibility of the VideoViews is being changed as well as the video description. We implemented the `videoAndTextChange` method which performs this functionality. See the following code for better understanding:

```

private void videoAndTextChange() {
    switch (btnClicked) {
        case 0:
            btn_back.setVisibility(View.INVISIBLE);
            videoPath =
"android.resource://com.janastarkova.bakalarka/" + R.raw.infarkt01;
            tv_infarkt01.setText(R.string.tv_infarkt01);
            break;
        case 1:
            btn_back.setVisibility(View.VISIBLE);
            videoPath =
"android.resource://com.janastarkova.bakalarka/" + R.raw.infarkt02;
            tv_infarkt01.setText(R.string.tv_infarkt02);
            break;
        case 2:
            videoPath =
"android.resource://com.janastarkova.bakalarka/" + R.raw.infarkt03;
            tv_infarkt01.setText(R.string.tv_infarkt03);
            break;
        case 3:
            videoPath =
"android.resource://com.janastarkova.bakalarka/" + R.raw.infarkt04;
            tv_infarkt01.setText(R.string.tv_infarkt04);
            break;
        case 4:
            videoPath =
"android.resource://com.janastarkova.bakalarka/" + R.raw.infarkt05;
            tv_infarkt01.setText(R.string.tv_infarkt05);
            btn_next.setVisibility(View.INVISIBLE);
            break;
    }
    uri = Uri.parse(videoPath);
    mVideoView.setVideoURI(uri);
}

```

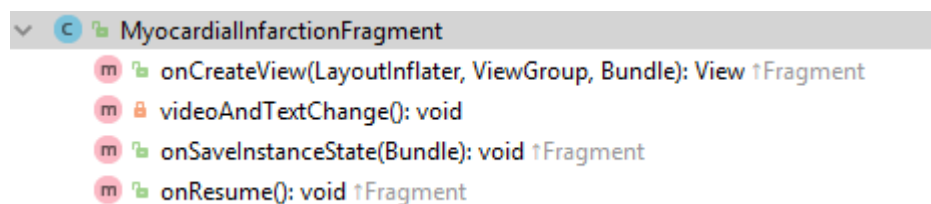
```

        mVideoView.start();
    }

```

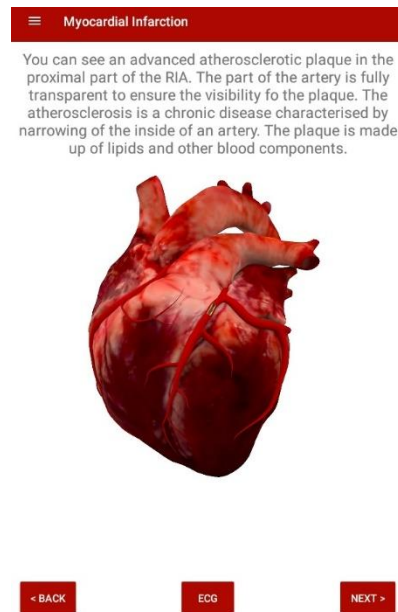
In addition, the user can see an ECG corresponding with the video he is looking at. We picked three ECG samples from the book EKG do kapsy (Haberl, 2012). The first of them represents the normal ECG record; the second picture displays the first stadium (up to 6 hours) of myocardial infarction with visible ST-segment elevations; the third video shows the second stadium with pathologic Q waves.

As can be seen in Picture 26, the Myocardial Infarction Fragment also contains onSaveInstanceState and onResume methods. The first of the mentioned is to save the value of the btnClicked variable and it ensures resuming the fragment in the same state in case of resuming the whole activity. The onResume method runs again the video linked to the displayed VideoView.



Picture 26: The structure of methods within the Myocardial Infarction Fragment

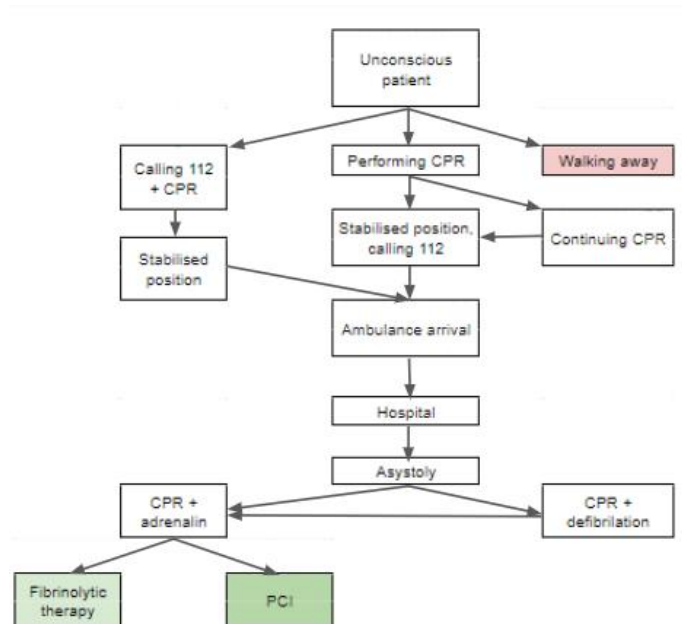
We also chose the RelativeLayout for this fragment with the following components – VideoView, TextView, three Buttons and ImageView (see Picture 27). The VideoView is again linked to a resource file by the code above. In this fragment, we are using TextView for describing each video. The descriptions were created according to the knowledge gained from the theoretical part (Chapter 2)



Picture 27: The structure of components within the layout file of the Myocardial Infarction Fragment

3.2.2.4 Quiz Game Fragment

The goal of the Quiz Game Fragment was to let the user practise their knowledge of acute myocardial infarction. It includes the basic first aid as well as advanced life support as the application is aimed for both laic audience and medical students. In the future, it could be customized for that specific target group with only several content changes. The myocardial infarction is revised in the form of story game which leads the user through several situations when he or she needs to decide on the most suitable option in order to save the patient's life and ensure that the recovery after the patient's infarction is as full as possible. See the Picture 28 for the flow of the game.



Picture 28: The flow of the quiz game. The green blocks mark a successful finish while the red block stands for a failure.

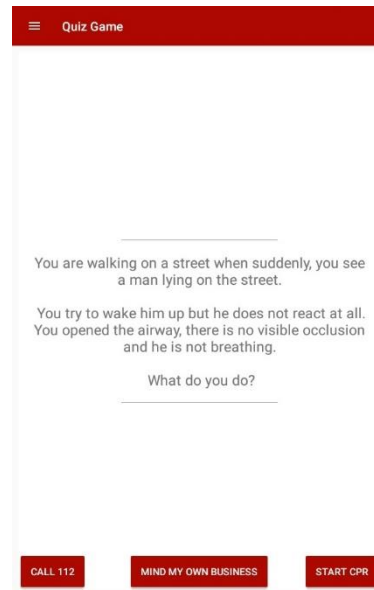
As can be seen in picture 29, the Quiz Game Fragment is composed of a variety of methods. It starts with the onCreateView method which sets up the fragment by calling the firstScreen method. There are three variables which we increment according to the number of clicks on each button. When the first screen of the game is initialized, the values all of the three variables are set to zero. Each method sets up the visibility of each button appropriately as well as the content of the text views.

```

QuizGameFragment
  m onCreateView(LayoutInflater, ViewGroup, Bundle): View tFragment
  m firstScreen(): void
  m dead(): void
  m successLeft(): void
  m successRight(): void
  m mona(): void
  m asystoly(): void
  m defibrillation(): void
  m traitement(): void
  m lya(): void
  m coro(): void
  m onSaveInstanceState(Bundle): void tFragment
  
```

Picture 29: The structure of the used methods within the Quiz Game Fragment

The layout is managed in a similar manner to previous fragments with a relative layout being its parent layout (see Picture 30). There are three buttons which are aligned to the bottom of the parent layout. The text views are used for describing the current game situation. The role of the views is simply to border the description text view. The visibility and text of Buttons and TextViews is set in each method mentioned above according to the content of the current game situation.



Picture 30: The screenshot of a first screen of the Quiz Game Fragment.

3.2.2.5 About Fragment

The AboutFragment contains only a simple TextView whose content informs the user about the purpose of this application and gives details about the author.

4 Discussion

According to our study, the variety of mobile applications focusing on 3D visualization of myocardial infarction is very limited. The available applications are often compromised in terms of the models' graphics and sometimes even provide inaccurate information. In addition, the user experience is quite poor as well as the interactivity and overall application function.

Regarding the outcomes of our bachelor thesis, all the objectives were fulfilled. Our application is available on Google Play and it is ready to be used. The great benefit of our application is its modularity which allows further extensions regarding both content and user experience.

We created a range of 3D models which are universal enough to be used on a variety of other platforms (such as iOS application, web application, augmented/virtual reality) in the future. Also, the models can be extended to visualize additional aspects, such as other heart diseases or even their treatment. With minor content adjustment for each target group, the application can be used by a laic audience as well as students of medicine or healthcare studies and professionals.

5 Proposal of Recommendations for Practise

Our application can be used by a variety of users. For each group, some minor content changes would be necessary in order to suit well the specific group. We already presented our application to the non-profit organisation Loono which would like to use it during their workshops about cardiovascular diseases.

With regards to future practise, we recommend to:

- optimise the content (as mentioned in the first paragraph),
- focus on the user experience,
- extend the first aid game,
- optionally broaden the whole application with additional modules.

Targeting focus on the user experience would in general mean making the application more interactive and friendlier to manipulate with. It could be done by adding animations to the application (view and fragments animations) as well as handling on touch events or even implementing the model itself in the application.

Extending the first aid game could include more possible scenarios, such as various symptoms of the acute myocardial infarction or giving the user more freedom in decision making. Also, it could be upgraded by creating time stress and making the user decide as quickly as possible.

The additional modules could firstly offer more types of myocardial infarction (teaching about the differences among the types). Secondly, there could be other heart conditions, including acute and chronical variations with their treatment options. Lastly, the whole application could be extended by other organs (such as the brain, kidney, liver, lungs, etc.). Despite such resource would undoubtedly be highly appreciated by students, it would be an enormous project which would (among others) require a team of skilled graphic designers, programmes and software engineers.

In addition, we would suggest not to confine the projects with the scope of an Android application as a web application or even an augmented/virtual reality game could bring the topic to its audience in a much more interactive and educational way.

6 Conclusion

This bachelor thesis was focused on the visualization of myocardial infarction in Android. Firstly, we described the pathophysiological changes in human heart during myocardial infarction, researched existing applications for human heart visualization and analysed the tools and formats suitable for heart visualization, thereby we met the first three objectives of the bachelor thesis.

Secondly, we focused on the main goal of our bachelor thesis, which was to design and develop a prototype of a mobile application. The prototype was supposed to simulate pathophysiological processes in the human heart during myocardial infarction. This objective was met to its full extent. We built a prototype of an Android application which visualizes the contractions of a healthy heart as well as tissue necrosis resulting from a myocardial infarction.

The benefit of our application is in its educational approach. Mobile applications are easily accessible to almost anyone and their popularity is rising even in such fields like education. Our application is already available on Google Play and organisations who set up educational workshops about cardiovascular diseases are interested in using it during their lectures.

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